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Life Cycle Engineering & Design Program

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ABSTRACT
During this decade, an increasing emphasis has been placed upon pollution prevention as a means to produce better products and systems while reducing environmental impacts from those systems. Several of the assessment tools and analytical techniques that have been used to do this, such as pollution prevention opportunity assessments, only look at on-site issues, ignoring impacts that might exist either upstream or downstream of the process. In order to capture these impacts, Life Cycle Assessment (LCA) was developed. LCA differs from other pollution prevention techniques in that it inventories all the resource, energy and cost inputs to a product, as well as the impacts from the associated waste streams, health and ecological burdens, and evaluates opportunities to improve the system on a life cycle scale.

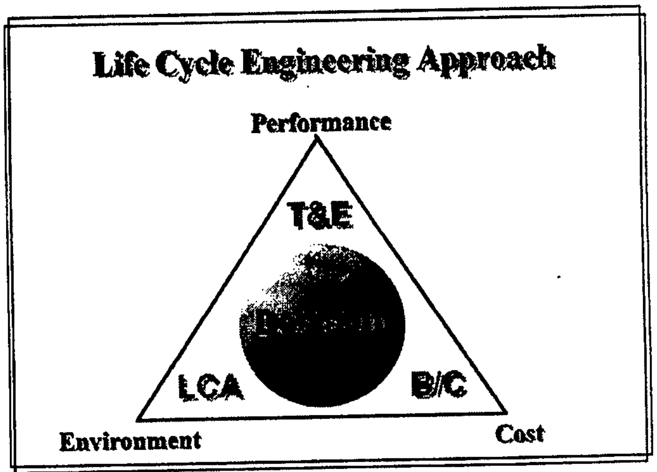
Co-sponsored by the Strategic Environmental Research & Development Program (SERDP) and EPA, the Life Cycle Engineering & Design (LCED) Program applies LCA methodology to DoD operations, systems, products and activities as a means to guide system design and aid life cycle decision-making. During the course of the LCED program, we have demonstrated that in some instances, a touted pollution prevention technology only transferred environmental burdens to another media or stage of the life cycle.

In order to illustrate the LCA methodology, case histories of three LCED projects will be presented: (1) Aircraft Radome Depainting; (2) Chemical Agent Resistant Coatings; (3) Energetic Materials for the GBU-24. Each project exhibits a distinct use of LCA methodology, which when applied to DoD operations is designed to unencumber military operations, enhance military systems' effectiveness, and improve the safety of personnel in meeting the Department's environmental obligations.

METHODOLOGY

Life Cycle Assessment, as EPA applies the term, consists of three overlapping analyses: Life Cycle Inventory (LCI); Impact Assessment (LCIA) and; Improvement Analysis (LCImA)[1]. However, the first step in every LCA is to set down the goals of the study and scope out the parameters. LCA is an expansive systems analysis methodology and the study must be carefully focused in order to acquire meaningful data. Therefore, the concept of LCA has goal definition and scoping as its center, a necessary first step before the analysis begins. The LCI is an inventory of resource, materials and energy consumed, as well as environmental releases produced for each stage in the life of a product, from raw material extraction to ultimate disposal (Note: EPA has published a manual for conducting LCIs[2]). After this information has been collected, an LCIA of the environmental and health effects related to resource consumption and environmental releases can be conducted. In fact, the LCIA begins to develop before the LCI is completed as impacts of priority concern are rapidly identified. The LCIA is both a quantitative and qualitative process to catagorize, characterize and value environmental impacts to form a basis for comparison between dissimilar impacts (e.g., global warming vs. ozone depletion). As the LCIA shapes up, the basis for the LCImA is formed, which identifies and provides an initial assessment of the changes needed to reduce environmental burdens of the product or process.

To the life cycle field, the LCED program brings the concept of balancing environmental concerns with requirements for operational performance and cost efficiency. Performance, Cost and Environment are the issues in determining the best solution in engineering and design of a product or process. That is to say, a failure in any of these key areas will have a direct negative impact the decision to proceed. Performance, Cost and Environment are also measured properly by inherently dissimilar metrics. For example, neither performance nor environment may be accurately measured in dollar signs. The diagram at right exhibits the concept of Life Cycle Engineering. The following discussion will show how this concept has been applied to three DoD operations.



Life Cycle Assessment Team
National Risk Management Research Laboratory

CHEMICAL AGENT RESISTANT COATING (CARC) LCA

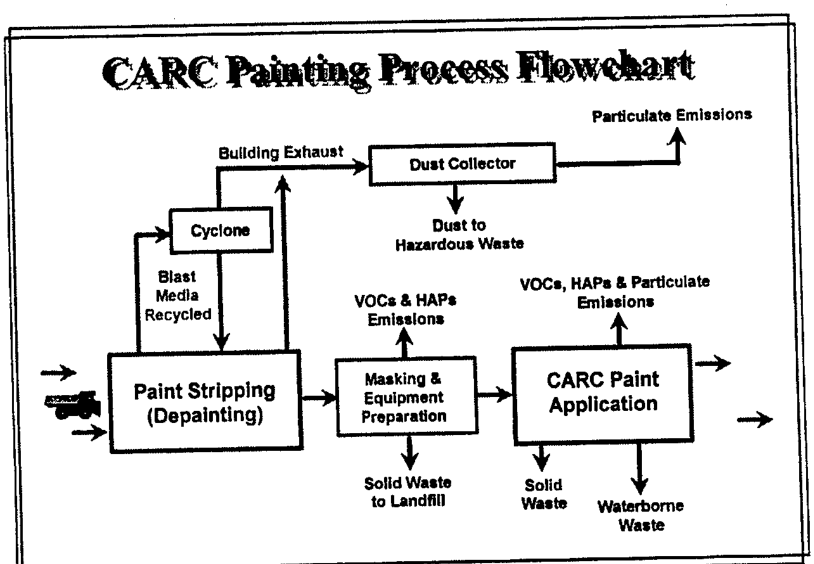
Two Army installations participated in the LCED study, and originally both had used Bink's Model 7 spray guns, but in accordance with recommendations from Pollution Prevention Opportunity Assessments (PPOA), had changed over to Mark 1 HVLP guns. Initially, this change led to better transfer efficiency, and the facilities saved up to $7,000 annually in reduced paint purchases. Over the longer term, however, problems cropped up. CARC is a much heavier, higher solids paint than found in commercial applications for which the HVLPs had been designed. Installations had problems with plugging, extended production times to deal with cleaning clogged equipment, and increased use of thinner.

Goal Definition and Scoping:

In this instance, the objective was to determine the combination of materials and equipment to paint CARC effectively at the lowest cost and minimal environmental impact. The CARC LCA was conducted for a baseline paint system, which included typical topcoat, thinner, and primer combinations determined from a survey of 13 major U.S. Army installations. The scoping survey was used to identify a typical CARC paint system, based on operations at Ft. Eustis, Virginia.

The Inventory (LCI):

The CARC LCI involved collection of environmental and utility data that describe the painting and depainting, and disposal of spent CARC and blast media, including the raw materials used, water and energy, air emissions, liquid wastes, and solid wastes. Where primary process information was missing, engineering estimates were made[3]. It was determined that the depainting and painting operations contributed greater than 80% of each of the following emissions from the total LCI: methyl isoamyl ketone, xylene, aromatic hydrocarbons, and



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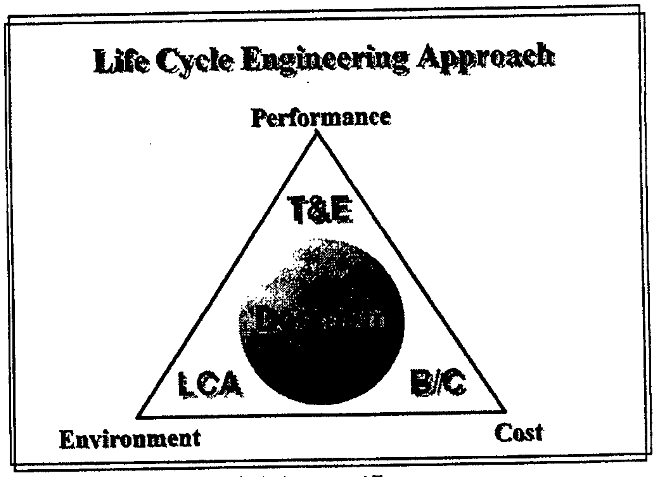

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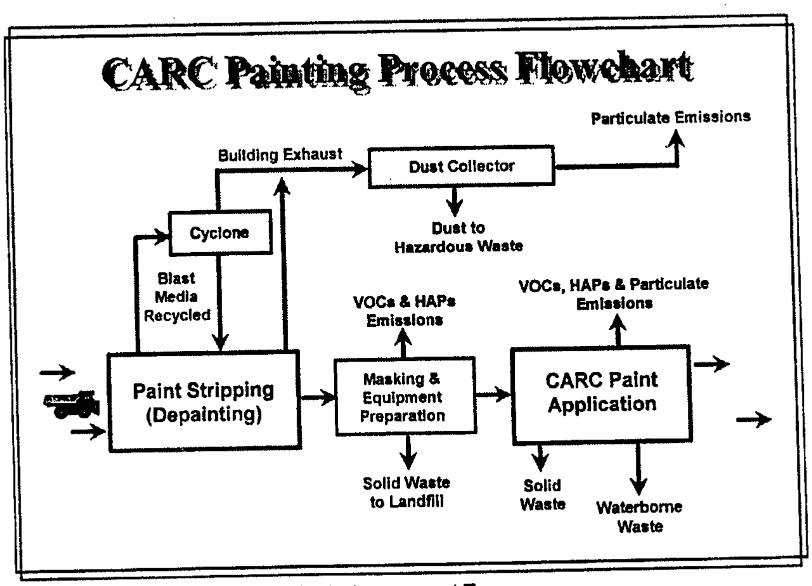

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hazardous solid wastes

The Impact Assessment (LCIA):

Since life cycle assessment is primarily about making comparisons and incorporating dissimilar impacts via the analysis, there has to be a methodology for making the comparisons on an equitable basis. An LCIA examines potential and actual environmental and human health effects from the use of resources (energy and materials) and environmental releases.[4] For CARC, nine impact categories were selected for characterization: smog formation, ozone depletion, acid rain, global warming, human health inhalation toxicity, terrestrial toxicity, aquatic toxicity, land use, and natural resource depletion. New impact equivalency units were created for some chemicals in the LCI, by using the hazard ranking approach described in an EPA report.[5] The valuation method used in this study is known as the Analytical Hierarchy Process (AHP).[6] Assignment of weights was done as a group exercise, where a four member team was asked to reach a consensus on the weight factors prior to their being entered into the model. Because the team included one cost engineer, one paints/coatings specialist, a civil engineer, and an ecologist, the valuation team mix, and the resulting weights, were considered reasonable.

The Improvement Assessment (LCImA):

On the basis of the LCIA, it was determined that the alternative with the best environmental potential included new spray equipment. The alternative spray equipment is the Can-am turbine HVLP, which uses turbine technology instead of the traditional method of passing compressed air through a conversion zone in order to convert high pressure, low volume air into HVLP. This technology decreases system turbulence which in turn reduces overspray significantly. The LCA found that a combination of an alternative primer, thinner and topcoat resulted in the lowest impact across the greatest number of impact categories, although it did not have the lowest impact for aquatic toxicity.

Performance Evaluation:

In order to test these conclusions, a technical evaluation was performed at two installations on test coupons and full-sized vehicles. The water-based primer performed well in moderate environments, but proved difficult to manage in high-humidity – although the painters felt confident that, given time to experiment further, they could use it efficiently. The evaluation supported the LCA's findings that cross-media impact of higher solvent usage by the HVLP guns over their predecessors would be eliminated by the new turbine-based HVLP systems. Further, the turbine HVLP dramatically improved transfer efficiencies, resulting in a 40% reduction in product use. Finally, the new system was well-received by the painters, who saw several benefits in terms of ease of cleanup and operations in the new systems.

Cost Assessment:

A life cycle cost assessment was conducted, comparing each alternative to the baseline system in place at Ft. Eustis. The assessment determined that, while the turbine-HVLP cost more than twice as much as the Mark 1 type HVLP system, the investment would be rapidly recovered in savings in product purchases. This alternative also exhibited a potential cost savings of $230,000 per year for each facility working at the Ft. Eustis level of painting operations.

Process Inconsistencies Between Sites:

The LCA showed that CARC paint is not consistently applied. In order to be able to force CARC topcoat through a typical HVLP gun, some facilities thinned it by as much as 20%, which dramatically increased VOC emissions. Two sites were using a lacquer thinner not approved for CARC. It seemed to perform better than the approved thinners in the painting process, but the installations had begun to notice a shortening of the life span of the CARC topcoat. Some installations would bypass the priming system entirely, using the CARC topcoat as a kind of "unicoat" material. Ironically, this practice substantially

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AIRCRAFT RADOME DEPAINTING LCA

The importance of the LCA approach in capturing upstream and downstream impacts can be demonstrated by an LCED project conducted for the Oklahoma City Air Logistics Center at Tinker AFB. OC-ALC painting personnel were looking for a drop-in replacement for methyl ethyl ketone (MEK) in the KC-135 radome depainting operation. OC-ALC depainted radomes in a shower of pure MEK, recycling the wash-off back into the system until it was removed as a sludge or vented off. This resulted in high VOC emissions and hazardous waste disposal costs.

Goal Definition and Scoping:

The scoping survey was brief, having only to identify the site specific aspects of the KC-135 radome depainting operations at the ALC. The objective was to develop a drop-in MEK replacement that would match or exceed performance and cost objectives, while eliminating the EPA-17 impact. This would allow the ALC to change over to a new depainting process without having to make a capital investment. Therefore, unlike the CARC example, this LCA would be used to develop an entirely new product and evaluate its potential. Unlike the CARC example, now the performance evaluation was conducted in concert with the LCI.

Performance Evaluation:

Our team proposed a solvent formulation, which we labeled PCB2, made up of propylene carbonate, n-methyl pyrrolidone (NMP), and dibasic esters (DBE) to eliminate MEK from the ALC operations without having to change equipment or procedures. The formulation was tested in lab scale to determine the best proportions of each chemical and then elevated to a coupon test. The PCB2 performed well on the coupons, which had been cut from condemned radomes, but while the performance was consistent with MEK, it was not superior. Tests were then conducted on two full-size radomes. One was depainted quickly and efficiently in comparable time to MEK, with no impact on the substrate. The second proved more difficult and took a ½ hour longer to complete. Painters informed the research team that this was not unusual performance for MEK, either, but there were insufficient funds available to depaint additional radomes to develop a more reliable statistical base.[7] However, both radomes were completely depainted, and there was no difficulty in repainting the radomes.

Cost Assessment:

In this instance, a cost comparison with MEK was simplified by the fact that no equipment would have to be purchased and maintained. In the circumstance of direct purchase, use and disposal cost of PCB2 versus MEK, the PCB2 formulation offered a cost savings of $30,000 annually. This savings would occur without any effort to recover and recycle the PCB2 (again, the ALC was looking for a comparison of a drop-in replacement – recycling would require a capital investment for distillation equipment), which might increase the savings over the life cycle..

The Inventory (LCI):

The PCB2 LCI involved collection of environmental and utility data that describe the manufacturing of these chemicals and projected level of operations at the ALC, recycling of depleted solvent and disposal of spent solvent, including the raw materials used, water and energy, air emissions, liquid wastes, and solid wastes. The ALC was emitting methyl ethyl ketone (MEK), an EPA-17 chemical, from KC-135 radome depainting operations at the rate of almost 8,500 gallons annually.

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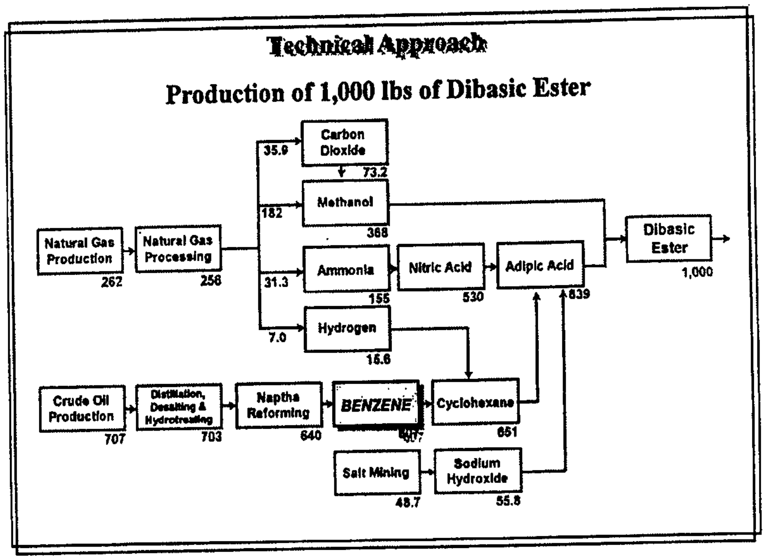
The Impact Assessment (LCIA):

In this example, the ALC wishes to eliminate an EPA-17 chemical from the depainting operation, as a part of an overall plan to reduce the reliance of their systems on EPA-17 materials. Therefore, the value of an EPA-17 impact in the system amounts to a "no-go" decision. The LCI did identify that the DBE used in PCB2 had benzene as an upstream precursor[8]. Since benzene is on the same EPA list, proceeding with this change might appear to move the EPA-17 impact from the operations stage to the materials manufacture stage. In this case, the cost of the benzene might increase over time, raising the cost of the PCB2 formulation.



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However, upon closer examination of the DBE production process, it was shown that the benzene is derived in process from naptha and is 95% consumed in the production of cyclohexane (see diagram above). Therefore, benzene is not purchased as a product, but is produced in process and is ultimately consumed in a contained reaction.

GBU-24 ENERGETICS MODULE

The GBU-24 bomb is consists of several components, the largest of which is the BLU-109 bomb body. The energetic material is royal demolition explosive (RDX), which has been difficult and environmentally costly to remove and dispose of in the demil process. Several alternative materials, including trinitroazetidine (TNAZ) based energetics are being tested as potential replacements. In this instance DoD required a baseline inventory by which to evaluate the environmental impacts of alternatives

Goal Definition and Scoping:

The goal is to establish the baseline for RDX in the BLU-109 application, which can then be used for environmental analyses of alternative materials in support of future life cycle engineering evaluations. The scoping survey identified the processe specific to Holston and McAlester AAP operations for production of the energetic and assembly/demil with the BLU-109. This study differs from the previous cases in that it seeks to establish a baseline for future studies and to provide the framework to compare a mature product system (RDX) with prototype systems (TNAZ). Therefore, this effort establish the inventory of RDX and TNAZ for a basic comparison without a performance evaluation.

The Inventory (LCI):

There were significant issues in acquiring data which were resolved by using conservative methods to close gaps in process energy data for a TNAZ-filled BLU-109. When data was not available for a TNAZ process subcomponent, it was assumed that the TNAZ variant would be no worse than the RDX, pending a future performance evaluation. Further, an allowance was made for a statistical error of up to 20% before any conclusions were drawn as a measure to reduce uncertainty.

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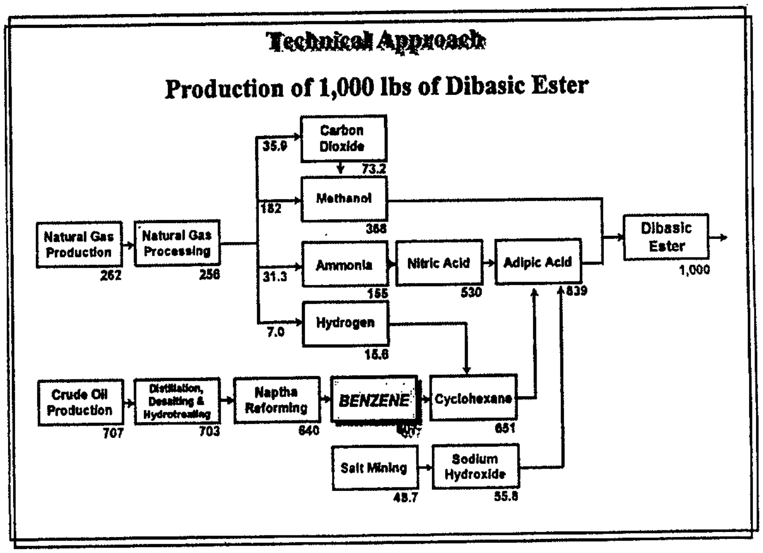

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The Impact Assessment (LCIA):
The study was able to establish a reliable baseline for RDX and developed a trade-off assessment in relationship to TNAZ process operations. While the generation of non-listed waste was relatively the same between RDX and TNAZ, TNAZ production generated significantly higher levels of listed waste (e.g., regulated under CERCLA, RCRA, TSCA, TRI, etc.) by a factor of 19 to 1 in total weight. Point of origin of these wastes also sifted from commercial suppliers in the RDX life cycle, to DoD facilities in the TNAZ life cycle.

CONCLUSION

Applying LCA methodology to CARC resulted in a series of discoveries concerning upstream and downstream impacts, problems in the field not previously known to the designers, variances in procedures and potential improvements for the system. These issues came to light precisely because LCA is more than a gate-to-gate analysis and they raise several concerns that can impact the engineering and design processes. For example, while the change to HVLP guns did result in a decreased use of CARC paint via improved transfer efficiency, that impact was offset by an increase in organic solvent usage and VOC emissions. It is due to the fact that LCA is a systems-wide analysis, that it can identify and "flag" these situations.

Under the LCED program, a report entitled, "Lessons Learned in Life Cycle Engineering" has been developed and is available for comment. The document details the life cycle engineering approach and the lessons taught to us by experience. It includes a summary and outline of the final deliverable for this program, the "Life Cycle Engineering Guide." Both documents are being developed to specifically serve the DoD facility manager and the DoD program manager. Members of the DoD community are invited to review and comment upon the lessons learned document and proffer comments and criticisms for the engineering guide.

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